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14. ABSTRACT

Partial acclimatization resulting from staging at moderate altitude reduces acute mountain sickness during rapid exposure to higher altitudes (e.g. 4300m). Whether staging also benefits endurance performance has not yet been scientifically evaluated. PURPOSE: Determine the effectiveness of staging at 2200m on time-trial (TT) performance of unacclimatized sea-level residents (SLR) during rapid exposure to 4300m. Ten healthy men (mean±SE: 21±1 yrs) performed 720 kJ cycle TTs at SL, and following ~2 hrs of exposure to 4300m (459 Torr) before (ALT-1) and after (ALT-2) living for 6d at 2200m (601 Torr). METHODS: Hemoglobin concentration ([Hb]), hematocrit (Hct), arterial oxygen saturation (SaO2), ratings of perceived exertion (RPE), and heart rate (HR) were measured before and during exercise. RESULTS: Compared to SL (73±6 min), TT performance was impaired ($P<0.01$) by 38.1±6 min at ALT-1 but only by 18.7±3 min at ALT-2. The 44±8% TT improvement at 4300m was directly correlated with increases in exercise SaO2 ($R=0.88$, $P<0.03$) but not to changes in [Hb] or Hct. In addition, RPE was lower (13±1 vs.16±1, $P<0.01$) and HR remained at ~148±5 beats•min-1 despite performing the TT at a higher power output ALT-2 than ALT-1 (120±7 vs 100±10

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Exercise Performance of Sea-Level Residents at 4300 m After 6 Days at 2200 m

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Partial acclimatization resulting from staging at moderate altitude reduces acute mountain sickness during rapid exposure to higher altitudes (e.g., 4300 m). Whether staging also benefits endurance performance has not yet been scientifically evaluated. ***Purpose:*** Determine the effectiveness of staging at 2200 m on time trial (TT) performance of unacclimatized sea-level residents (SLR) during rapid exposure to 4300 m. There were 10 healthy men (mean ± SE: 21 ± 1 yrs) who performed 720 kJ cycle TT at SL and following ~2 h of exposure to 4300 m (459 Torr) before (ALT-1) and after (ALT-2) living for 6 d at 2200 m (601 Torr). ***Methods:*** Hemoglobin concentration ([Hb]), hematocrit (Hct), arterial oxygen saturation (S_aO_2), ratings of perceived exertion (RPE), and heart rate (HR) were measured before and during exercise. ***Results:*** Compared to SL (73 ± 6 min), TT performance was impaired ($P < 0.01$) by 38.1 ± 6 min at ALT-1, but only by 18.7 ± 3 min at ALT-2. The 44 ± 8% TT improvement at 4300 m was directly correlated with increases in exercise S_aO_2 ($R = 0.88$, $P < 0.03$), but not to changes in [Hb] or Hct. In addition, RPE was lower (13 ± 1 vs.16 ± 1, $P < 0.01$) and HR remained at ~148 ± 5 bpm despite performing the TT at a higher power output during ALT-2 than ALT-1 (120 ± 7 vs.100 ± 10 W, $P < 0.01$). ***Conclusion:*** Partial acclimatization resulting from staging attenuated the impairment in TT performance of SLR rapidly exposed to 4300 m. The close association between improved TT performance and changes in exercise S_aO_2, compared to a lack of association with changes in [Hb] or Hct, suggest ventilatory acclimatization may have been the major factor contributing to the performance improvement.

Keywords: exercise, high altitude, staging, moderate altitude, acclimatization.

RESIDING FOR SEVERAL days at a moderate altitude prior to ascending to a higher elevation or "staging" is a universally accepted acclimatization strategy (8,15,17,18). In general, an ideal staging altitude for unacclimatized sea-level residents (SLR) should be high enough to initiate physiological responses that induce beneficial changes such as an increase in arterial oxygenation, but not so high as to cause acute mountain sickness (AMS) or sleep disruption (15,18). The expectation is that the modest beneficial changes induced during staging will transfer to the higher altitude and thereby help avoid severe symptoms of AMS and large reductions in endurance exercise performance that would otherwise occur with rapid, non-staged ascent (8,10).

Broad guidelines exist that recommend various moderate altitude staging elevations and durations that might be beneficial at a given higher altitude (9,15). However, much of this information apparently has been based mainly on older, limited, and likely anecdotal reports that have used only the reduction in AMS symptoms at the higher altitudes to determine the success of a given staging strategy (8,9,12,21). Depending on factors such as the staging elevation(s) (e.g., 1500 to 2500 m) and duration (e.g., > 4 d), the reported effectiveness for reducing the incidence or severity of AMS at higher altitudes typically ranges from 20 to 100% (8,12,18,21).

The beneficial changes induced by living for several days at moderate altitude have long been known to be quite effective for attenuating the symptoms of AMS (8,12). Whether staging would also minimize the endurance performance decrement at high altitude is largely unknown. Consistent with a performance benefit are recent reports indicating that moderate-altitude residents who lived for 21 mo at 2200 m and who were considered fully acclimatized to moderate altitude did not experience AMS (16) or a decline in exercise intensity during endurance exercise (11) when rapidly exposed to 4300 m. Nevertheless, the effect of only partial acclimatization resulting from living for several days at moderate altitude on endurance performance at high altitude has been neither evaluated quantitatively nor assessed independently of changes in AMS. The primary objective of this study, therefore, was to determine for the first time the effectiveness of staging for 6 d at a moderate altitude of 2200 m on prolonged endurance performance at 4300 m without concomitant changes in AMS. It was hypothesized that the decrement in prolonged time-trial performance at high altitude would be attenuated by partial acclimatization resulting from staging at moderate altitude.

METHODS

The volunteers were 10 SLR who were active duty male military personnel assigned to the U.S. Army Natick

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Soldier Center. All had been living at low altitudes (< 1000 m) for at least 3 mo prior to the start of the study. The age, height, and weight of the volunteers were (mean ± SE): 21 ± 1 yr, 177 ± 3 cm, and 78 ± 4 kg, respectively. In addition to participating in Army physical training for 3-4 d • wk^{-1} (e.g., running, calisthenics, backpacking), the men reported regularly participating for at least 1 h • d^{-1} for 23 ± 5 d • mo^{-1} in activities such as basketball, weightlifting, football, baseball, and competitive skateboarding. All provided verbal and written consents after being fully informed of the nature of the study and its possible risks and benefits. The study was approved by the institutional review boards of the U.S. Army Research Institute of Environmental Medicine (USARIEM), U.S. Army Medical Research and Materiel Command, Human Research Protection Office, and the U.S. Air Force Academy (USAFA).

Testing Phases, Facilities, and Experimental Design Overview

This study was organized into three distinct phases at three different test facilities over a period of 12 wk in the following order: 1) a baseline sea-level and prestaging (ALT-1) high-altitude assessment phase at USARIEM, Natick, MA; 2) a moderate altitude acclimatization staging phase at the USAFA (Colorado Springs, CO; 2200 m); and 3) a post-staging (ALT-2) high-altitude phase at the summit of Pikes Peak (Colorado Springs, CO; 4300 m) (**Fig. 1**). The same equipment that was used at USARIEM also was used at the USAFA and on the summit. During all phases, the temperature and relative humidity during testing were 21 ± 3°C and relative humidity 45 ± 10%, respectively.

Exercise assessments, AMS, and resting cardiorespiratory and blood measurements occurred on multiple occasions at USARIEM during the baseline phase at sea level (SL, P_B = ~760 mmHg) or during two acute hypobaric chamber exposures (1 and 5 h) that were at the same P_B as at the summit of Pikes Peak (i.e., 459 mmHg). Hypobaric chamber decompression from 760 mmHg to 459 mmHg took ~10 min. After all testing was completed at USARIEM the volunteers were flown nonstop via commercial airline to Colorado (~6 h) in groups of two on consecutive days to participate in the staging phase that was conducted over a 6-d period in the Human Performance Laboratory (HPL) and its surrounding rooms (~601 mmHg) at the USAFA. Sending only two volunteers at a time to Colorado allowed the subsequent high-altitude timing and sequence of procedures at ALT-2 to be maintained identically to those used at ALT-1 at USARIEM. The number of days between ALT-1 and ALT-2 testing ranged from 34 to 52 d (median: 46 d) among volunteers.

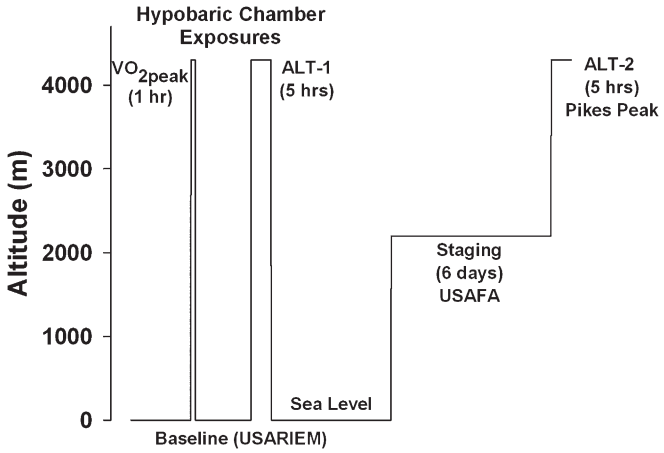

Fig. 1. Study design: baseline was conducted at the USARIEM. During baseline, volunteers were tested at sea level and at 4300 m (ALT-1). After sea level and ALT-1 testing were completed, the volunteers were transported to the USAFA (2200 m), where they stayed for 6 d before being driven to the summit of Pikes Peak (4300 m) and were then tested for 5 h (ALT-2). The procedures and their time of administration were identical for ALT-1 and ALT-2; 34 to 52 d (median: 46 d) separated ALT-1 and ALT-2.

In addition to laboratory-based testing procedures, all volunteers participated in two to four supervised hikes (< 3 h) on trails located on the USAFA base to simulate military scouting patrols. At 0600 of the 7th day at the USAFA, the volunteers were driven (~1.5 h) to the summit of Pikes Peak. The volunteers were instructed not to perform any non-study related leg exercise for 24 h before each test session. Volunteers were allowed to eat ad libitum throughout the entire study, except when they were provided with two commercially available energy bars and fruit juice (food composition = 510 kcal, 14 gm fat, 65 gm carbohydrate, 32 gm protein) at 1 to 2 h prior to the beginning of each of the long endurance performance assessments.

Procedures

Incremental, progressive exercise bouts to volitional exhaustion on an electromagnetically braked cycle ergometer (model: Excalibur, Lode BV, Groningen, The Netherlands) were used to assess peak oxygen uptake ($\dot{V}O_{2peak}$) at USARIEM twice while at SL (1st practice/familiarization, 2nd definitive) and once during a 1-h hypobaric chamber exposure to 4300 m. Continuous measurements of O_2 uptake were obtained throughout the tests using a calibrated metabolic cart (True Max 2400, Parvo Medics, Sandy, UT). For each test, the volunteer began pedaling at ~80 rpm at 50 W for a 3-min warm up. The power output was then increased to 100, 130, and 160 W in 2-min increments. Thereafter, power output was increased by 15 W each min until O_2 uptake failed to increase or the volunteer could not continue despite strong verbal encouragement. Data from the $\dot{V}O_{2peak}$ tests were used to determine the steady-state power outputs during cycle maintenance training, the long endurance performance assessment, and to estimate the mean power output used during the time trial (TT) (1).

Cycle maintenance training was conducted using electromagnetically braked cycle ergometers (model: Corival, Lode BV, Groningen, The Netherlands) four times during the USARIEM baseline phase (SL only) and five times during the USAFA staging phase (days 1, 2, 4-6). Each training session consisted of 5 min of warm up at 50 W, 30 min of steady-state (SS) exercise at an individually

determined low-intensity fixed power output (44 ± 2% of SL $\dot{V}o_{2peak}$) and, after a 5 min break, a short (~15 min) 180 kJ TT segment (except on the last day at the USAFA to allow adequate rest prior to cycling at ALT-2 the next morning). The goal of the nine training sessions over the 12-wk study period was to maintain familiarity with the cycling procedures.

Long endurance performance was determined using an electromagnetically braked cycle ergometer (model: Excalibur, Lode BV, Groningen, The Netherlands) three times during the USARIEM baseline assessment phase (twice at SL and once beginning at ~2 h of exposure to hypobaric hypoxia) and once beginning at ~2 h of arriving at the summit of Pikes Peak. Each long endurance performance assessment consisted of two major segments after 5 min of warm-up at 50 W: 1) SS exercise for 20 min at ~44 ± 2% (low intensity) followed by 20 min at ~60 ± 2% (high intensity) of their altitude-specific $\dot{V}o_{2peak}$ and after a 5 to 10 min rest, 2) a 720-kJ maximum effort TT. The better TT performance at SL was used as the SL baseline value. For all tests and throughout the duration of each test, water was provided ad libitum. These procedures and the justification for their use have previously been described in detail (10).

Briefly, the power outputs used for the low- and high-intensity steady-state exercise bouts were identical during ALT-1 and ALT-2. After the short rest period at the end of high-intensity SS exercise, the volunteers were asked to complete the 720-kJ TT as fast as possible. They were allowed to alter pedaling speed and adjust power output by any watt increment at any time. To minimize possible interference with volunteer concentration and cycling pace, O_2 uptake measurements and blood samples were not obtained during the TT. Volunteers were continuously informed of the volume of work performed and remaining (via computer screen); but not the time elapsed. The 720-kJ TT segment provided the primary outcome variable to determine if partial acclimatization acquired during staging improved endurance performance at high altitude.

Heart rate via HR watch (Polar Electro, Woodbury, NY), arterial oxygen saturation (S_aO_2) via noninvasive finger pulse oximetry (Model 8600, Nonin Medical, Inc., Plymouth, MN), and ratings of perceived exertion [RPE, 6 to 20 Borg scale (5)] were determined at the end of every stage of the $\dot{V}o_{2peak}$ tests, at 25 min during cycle maintenance training, at 15 min during SS exercise, and every 5 min during the TT.

AMS was determined from information gathered using a subset of the Environmental Symptoms Questionnaire (ESQ) and the Lake Louise AMS Scoring System (LLS) administered using a personal digital assistant (PDA; HP model: iPAQ). The ESQ was a shortened version (4) of the self-reported, 68-question inventory used to document symptoms induced by altitude (20). A weighted average of scores from nine symptoms (headache, lightheaded, dizzy, etc.) designated "AMS-C" was calculated. The weighted scores ranged from 0 (no symptoms) to 5 (severe symptoms). A weighted AMS-C score equal to or greater than 0.70 indicates the presence of AMS. The LLS consists of a six-question, self-reported assessment of AMS symptoms (19). Total LLS scores that include headache and are ≥3 (range: 0 to 18) are diagnostic of AMS. The questionnaires were administered during rest in the mornings at SL, ALT-1, USAFA, and ALT-2. The questionnaires were also administered within an hour of initiating each long endurance performance assessment.

Measures of resting partial pressures of end-tidal carbon dioxide ($P_{ET}co_2$) and oxygen ($P_{ET}o_2$), S_aO_2, and heart rate (HR) were conducted with the volunteers awake, seated, relaxed, and fasting for at least 2 h During these tests, the volunteers were connected for 15-20 min to a breathing circuit by a rubber mouthpiece and nose clip and to a finger pulse oximeter unit (Model 8600, Nonin Medical, Inc., Plymouth, MN) to record S_aO_2 and HR. $P_{ET}co_2$ and $P_{ET}o_2$ were determined using a metabolic cart (Vmax 229, Sensormedics Inc., Yorba Linda, CA). All resting measurements were determined in the morning at SL and during ALT-1 and ALT-2 on the same days and just prior to the long endurance performance assessments.

Resting venous arm blood samples (5 ml) were obtained at SL, ALT-1, and ALT-2. Each 5-ml sample was analyzed immediately in duplicate for the measurement of hemoglobin concentration ([Hb]), hematcrit (Hct), and glucose using an iStat portable clinical analyzer (Abbott Diagnostics, Abbott Park, IL). Changes in [Hb] and Hct were used to estimate the percentage plasma volume reduction from SL resulting from staging (7). Arterial oxygen content (C_aO_2; ml • dl^{-1}) was calculated as the product of S_aO_2 (%), [Hb] (g • dl^{-1}), and 1.34 mlO_2 • gHb^{-1}.

Analysis of variance with repeated measures on one factor (day) was used for performance, physiological, and blood values (Statistica v7.1, Statsoft, Tulsa, OK). Post hoc (Newman-Keuls) calculations were performed when appropriate. Regression analyses were used to determine relationships between physiological measures (e.g., S_aO_2) and exercise performance (e.g., TT duration). Statistical significance was accepted when $P \leq 0.05$. All values are expressed as means ± SE unless otherwise indicated.

RESULTS

Peak oxygen uptake declined 31 ± 2% from 3636 ± 215 ml • min^{-1} at SL to 2693 ± 89 ml • min^{-1} at 4300 m ($P < 0.01$). At $\dot{V}o_{2peak}$, there were also declines ($P < 0.01$) in W_{peak} (283 ± 10 to 234 ± 7 W) and S_aO_2 (97 ± 1 to 75 ± 2%). In contrast, there was no difference in HR_{peak} (186 ± 3 vs. 183 ± 3 bpm).

Cycle Maintenance Training

Throughout the SL and staging phases, SS power output was maintained for 30 min at 116.0 ± 8 W (or 44 ± 2% of $\dot{V}o_{2peak}$ and 41 ± 2% of W_{peak}). There were no differences between SL and staging days for HR or RPE (**Table I**). There also were no changes in 180-kJ TT performance times, HR, or RPE between SL and staging days. For both SS and 180-kJ TT exercise, S_aO_2 was lower

TABLE I. STEADY-STATE AND TIME TRIAL EXERCISE VALUES DURING CYCLE MAINTENANCE TRAINING.

	SL	STG1	STG2	STG4	STG5	STG6
SS						
HR (bpm)	133 ± 6	132 ± 5	127 ± 6	133 ± 4	130 ± 5	126 ± 5
S_aO_2 (%)	96 ± 1	89 ± 1*,**	91 ± 1*	92 ± 1*	92 ± 1*	92 ± 1*
RPE	9 ± 1	8 ± 1	8 ± 1	8 ± 1	8 ± 1	8 ± 1
TT						
TT (min)	16.0 ± 1	14.7 ± 1	15.1 ± 1	15.8 ± 1	16.4 ± 1	
HR (bpm)	176 ± 5	173 ± 3	175 ± 3	172 ± 3	167 ± 5	
S_aO_2 (%)	96 ± 1	88 ± 1*,**	91 ± 1*	91 ± 1*	90 ± 1*	
RPE	14 ± 1	14 ± 1	13 ± 1	13 ± 1	13 ± 1	

Values are means ± SE; SS = steady-state exercise at 44% $\dot{V}O_{2peak}$; TT = time trial, 180 kJ; HR = heart rate; S_aO_2 = arterial oxygen saturation; RPE = ratings of perceived exertion. Data in the table are for the 25th min of SS exercise or for the last 5 min of the TT, respectively. SL = sea level (data from final SL training day); STGx = Day of staging at moderate altitude; * $P < 0.01$ lower than SL; ** $P < 0.05$ STG1 lower than all other STG days; TT (min) = time in minutes to complete the TT.

on each staging day compared to SL and was lower on staging day 1 compared to each of the other staging days.

Long Endurance Performance: Steady-State and 720-kJ TT

Steady-state power outputs during the long endurance performance test were intentionally reduced ($P < 0.01$) from SL for ALT-1 and ALT-2 during low (116.0 ± 8 to 72.5 ± 5 W) and high (158.0 ± 7 to 116.0 ± 8 W) intensity SS exercise to maintain an equivalent altitude-specific % $\dot{V}o_{2peak}$ exercise intensities (at ~44% and ~60%, respectively) prior to the 720-kJ TT (10). **Table II** shows the HR, S_aO_2, and RPE responses to the identical low (72.5 ± 5 W) and high (116.0 ± 8 W) intensity SS exercise power outputs at high altitude during ALT-1 and ALT-2. Each of the measures was significantly improved or tended to improve from ALT-1 to ALT-2 for both intensity levels.

At ALT-1, two volunteers were unable to complete the entire 720-kJ TT of the long endurance performance test due to extreme leg fatigue. One completed 59% or 423 kJ and the other 49% or 351 kJ. Both volunteers (and all others) were able to complete the 720-kJ at SL and ALT-2. In order to meaningfully compare TT results for these two volunteers only, all their data collected at SL, ALT-1, and ALT-2 were compared only up to 423 kJ and 351 kJ, respectively. Thus, for the entire group, the mean TT completed in each phase was 653 ± 47 kJ. Time-trial performance durations were 61.0 ± 17% (38.1 ± 6 min) longer during ALT-1 and 26.0 ± 4% (18.7 ± 3 min) longer during ALT-2 compared with SL (**Table III** and **Fig. 2**). Moreover, the volunteers began the ALT-1 and ALT-2 long endurance performance tests with nearly identical resting blood glucose levels. These results indicate that 44.2 ± 8% of the initial TT deficit as measured during ALT-1 was eliminated by ALT-2. It is important to note that TT performance was improved for each of the 10 volunteers by an average of 19.5 ± 6 min at ALT-2 compared to ALT-1 ($P < 0.01$).

Mean power output used during the TT was lower ($P < 0.01$) during ALT-1 and ALT-2 compared to SL, but was 20% higher ($P < 0.01$) at ALT-2 compared to ALT-1. Power output expressed as %SL W_{peak} also was similarly altered between test days. The values for changes in estimated $\dot{V}o_2$ closely tracked the results for changes in watts used expressed either in absolute terms or as %SL $\dot{V}o_{2peak}$. That is, from SL to ALT-1 or ALT-2, mean TT $\dot{V}o_2$ values were reduced, but higher at ALT-2 than ALT-1 ($P < 0.01$).

TT S_aO_2 was reduced ($P < 0.01$) from SL to ALT-1. S_aO_2 tended to increase at ALT- 2 ($P < 0.07$) compared to

TABLE II. STEADY-STATE EXERCISE VALUES DURING THE LONG ENDURANCE TEST AT HIGH ALTITUDE BEFORE AND AFTER STAGING AT MODERATE ALTITUDE.

Activity	Measurement	ALT-1	ALT-2
Low Intensity Exercise	HR (bpm)	122.8 ± 5	118.5 ± 4†
(72.5 ± 5 W)	S_aO_2 (%)	75.0 ± 2	77.2 ± 1*
(~44% $\dot{V}O_{2peak}$)	RPE	8.4 ± 1	7.4 ± 1
High Intensity Exercise	HR (bpm)	147.8 ± 5	140.1 ± 5*
(116.0 ± 8 W)	S_aO_2 (%)	75.6 ± 2	76.8 ± 1
(~60% $\dot{V}O_{2peak}$)	RPE	11.7 ± 1	9.2 ± 1*

Values are means ± SE; ALT-1 = 5-h hypobaric chamber exposure before staging; ALT-2 = 5-h Pikes Peak exposure after staging; $\dot{V}O_{2peak}$ = peak oxygen uptake; HR = heart rate; S_aO_2 = arterial oxygen saturation; RPE = ratings of perceived exertion. * $P < 0.01$ compared to ALT-1; † $P = 0.068$ compared to ALT-1.

TABLE III. TIME-TRIAL VALUES DURING THE LONG ENDURANCE TEST AT SEA LEVEL AND AT HIGH ALTITUDE BEFORE AND AFTER STAGING.

	SL	ALT-1	ALT-2
TT Duration (min)	73.2 ± 6	111.4 ± 6*	91.9 ± 7*,†
Power Output (W)	150.0 ± 5	100.4 ± 10*	120.2 ± 7*,†
Power Output (%SL W_{peak})	52.9 ± 2	37.9 ± 4*	45.4 ± 3‡
$\dot{V}O_2$ (ml · min^{-1})	2280 ± 147	1478 ± 167	1765 ± 131*,†
$\dot{V}O_2$ (%SL $\dot{V}o_{2peak}$)	59.2 ± 2	37.2 ± 3*	45.3 ± 3*,†
S_aO_2 (%)	96.5 ± 1	74.1 ± 1*	75.7 ± 1*
RPE	13.2 ± 1	15.5 ± 1*	13.0 ± 1
HR (bpm)	160.3 ± 5	147.7 ± 6§	148.4 ± 4§
HR (%SL HR_{peak})	85.4 ± 2	78.9 ± 3§	79.1 ± 2§

Values are means ± SE; SL = sea level; ALT-1 = 5-h hypobaric chamber exposure before staging; ALT-2 = 5-h Pikes Peak exposure after staging; W = watts; $\dot{V}O_2$ = oxygen uptake; %SL W_{peak}, %SL $\dot{V}o_{2peak}$, %SL HR_{peak} = percentage of SL_{peak} values for watts, oxygen uptake, and heart rate, respectively, that was used during the TT. * $P < 0.01$ from SL; † $P < 0.01$ from ALT-1; ‡ $P < 0.04$ from SL and ALT-1; § $P < 0.05$ from SL.

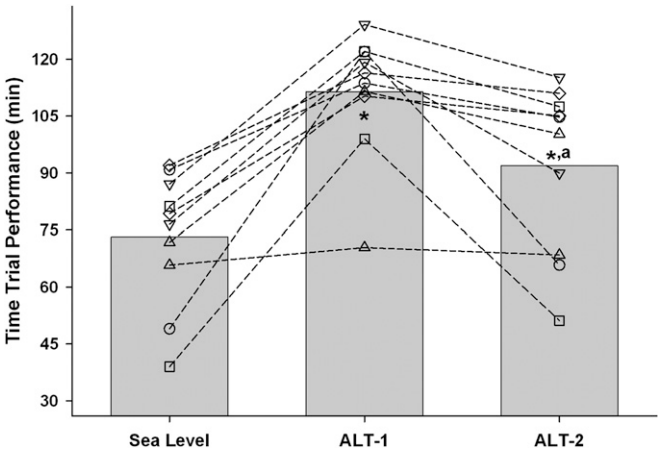

Fig. 2. Effect of staging on time-trial performance. The time-trial performance data are presented for each of the 10 individuals (lines) and as group means (bars) at sea level, and at 4300 m before (ALT-1) and after (ALT-2) staging.

ALT-1 despite the TT being performed at a higher power output at ALT-2. Individual changes in exercise S_aO_2 during the SS bouts and the TT were directly related to the individual absolute or percentage improvements in TT performance from ALT-1 to ALT-2 (**Fig. 3**). The close association between higher exercise S_aO_2 and improved TT performance ($R = 0.88$, $P < 0.03$) suggest ventilatory acclimatization was a major contributing factor for improved TT performance after staging. None of the increases in [Hb], Hct, C_aO_2, or the calculated decreases in plasma volume were significantly related to changes in TT performance (all $R \leq 0.33$, $P > 0.05$).

RPE during the TT increased from SL to ALT-1 ($P < 0.01$). Despite exercising at a power output that was approximately 20% higher at ALT-2 than ALT-1, RPE was reduced ($P < 0.01$). Exercise HR was reduced from SL to ALT-1 and ALT-2 ($P < 0.01$), but did not change from ALT-1 to ALT-2. There were no statistically significant relationships between changes in TT performance and RPE or HR from ALT-1 to ALT-2.

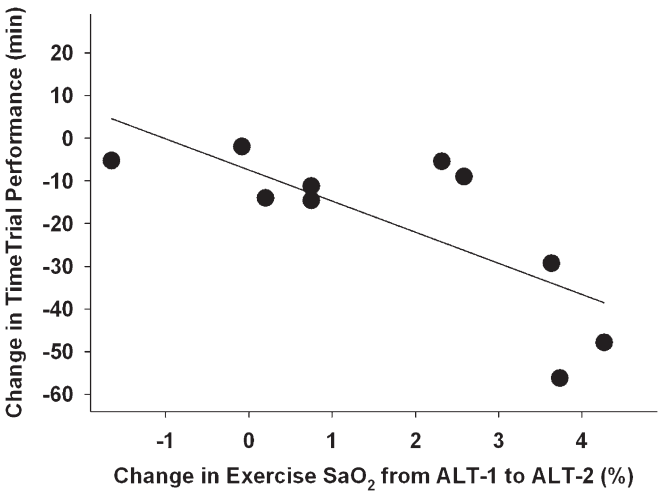

Fig. 3. Changes in time-trial performance and arterial oxygen saturation (S_aO_2) during exercise. Change (Δ) in TT performance from ALT-1 to ALT-2 = $-3.51 + (\Delta 45\% S_aO_2 * -4.92) + (\Delta 65\% S_aO_2 * 1.28) + (\Delta TT S_aO_2 * -4.28)$; $R = 0.88$; $P < 0.03$.

Acute Mountain Sickness

At SL and during each of the 6 staging days, the mean AMS-C value of the ESQ and the mean LLS value were always below the AMS criterion scores of 0.70 and 3.0, respectively. On an individual basis, the ESQ determined that none of the volunteers had AMS during staging, whereas the LLS determined that there was mild AMS in four volunteers on staging day 1 (scores: 3,3,4,6), in three volunteers on staging day 2 (scores: 3,4,9), and in two volunteers on staging day 3 (scores: 3,4). After staging day 3, no volunteers reported having AMS regardless of the scoring system used.

At high altitude, the mean group AMS-C score calculated from the ESQ indicated that there was an absence of AMS prior to the start of exercise during ALT-1 (0.27 ± 0.11) and ALT-2 (0.31 ± 0.17). Similar group results were obtained using the LLS: 0.55 ± 0.31 during ALT-1 and 0.64 ± 0.37 during ALT-2. On an individual basis, the ESQ indicated that the same volunteer had AMS just prior to exercise at ALT-1 (AMS-C score = 1.094) and ALT-2 (AMS-C score = 1.649.) The LLS also identified that volunteer as having AMS (score = 3), but at ALT-2 only.

Resting Cardio-Respiratory Measures and Blood Analyses

From ALT-1 to ALT-2, there were decreases in resting $P_{ET}CO_2$ and HR, and increases in $P_{ET}O_2$ and S_aO_2 (**Table IV**). Both [Hb] and Hct were slightly higher ($P < 0.05$) at ALT-2 (15.3 ± 0.3 g • dl^{-1}; $45.1 \pm 1\%$) than at SL (14.7 ± 0.2 g • dl^{-1}; $43.1 \pm 1\%$) or ALT-1 (14.8 ± 0.3 g • dl^{-1}; $43.5 \pm 1\%$). The increased values for [Hb] and Hct were associated with an estimated % plasma volume reduction ($P < 0.01$) of $7 \pm 2\%$ from SL to ALT-2 (7). Arterial oxygen content was reduced ($P < 0.01$) from SL (19.1 ± 1.0 ml • dl^{-1}) to ALT-1 (15.9 ± 1.4 ml • dl^{-1}) and ALT-2 (17.1 ± 1.1 ml • dl^{-1}), and was higher ($P < 0.01$) on ALT-2 compared to ALT-1. Resting blood glucose just prior to exercise was not different from ALT-1 (5.37 ± 0.2 mmol) to ALT-2 (5.36 ± 0.2 mmol).

DISCUSSION

To our knowledge, this study is the first to present a quantitative appraisal of the effect of staging at a moderate

TABLE IV. RESTING CARDIO-RESPIRATORY MEASURES BEFORE AND AFTER MODERATE ALTITUDE STAGING.

Measurement	ALT-1	ALT-2
HR (bpm)	71.6 ± 2	65.1 ± 2*
$P_{ET}CO_2$ (mmHg)	39.1 ± 1	32.8 ± 1*
$P_{ET}O_2$ (mmHg)	47.7 ± 1	50.2 ± 1*
S_aO_2 (%)	80.1 ± 1	83.1 ± 1*

Values are means ± SE; ALT-1 = 5-h hypobaric chamber exposure before staging; ALT-2 = 5-h Pikes Peak exposure after staging; $P_{ET}CO_2$ and $P_{ET}O_2$ = partial pressure of end-tidal CO_2 and O_2, respectively; S_aO_2 = arterial oxygen saturation. * $P < 0.01$ compared to ALT-1.

altitude on prolonged endurance performance at a higher elevation. Our results clearly indicate that living for only 6 d at 2200 m enhanced TT performance of each of 10 previously unacclimatized SLR during exposure to 4300 m. Compared to the TT duration of 73 min at sea level, the TT at 4300 m took about 38 min longer to complete before staging, but only about 19 min longer after staging. This finding shows that partial acclimatization resulting from staging at 2200 m eliminated nearly half of the initial TT impairment at 4300 m. Moreover, two individuals who completed only ~55% of the TT at 4300 m before staging completed the entire TT after staging. It is also important to emphasize that the TT performance results at high altitude were not confounded by changes in the incidence or severity of AMS symptoms and that there was only mild AMS in a few individuals during early exposure to 2200 m. Collectively these findings indicate that the staging elevation and duration combination used provided a highly effective means for attenuating the large endurance performance decrement during early exposure to 4300 m.

Residence at a given altitude induces a variety of physiological compensatory adjustments characteristic of altitude acclimatization that minimize the impact of hypoxemia and that are generally proportional to the altitude and time spent at that elevation (6,17,22). In the current study, traditional ventilatory and blood markers of acclimatization such as $P_{ET}CO_2$, $P_{ET}O_2$, S_aO_2, and [Hb] (22) were monitored at rest or during standardized exercise before, during, and after 6 d of staging. The $P_{ET}CO_2$ reduction, $P_{ET}O_2$, and S_aO_2 increases and the small but statistically significant hemoconcentration observed in response to 4300 m after staging indicate that at least partial acclimatization occurred while living at moderate altitude (6,13,17). Additional evidence of the benefit of moderate altitude acclimatization was manifested as generally lower RPE or HR and ~2–3% higher S_aO_2 for the same (i.e., SS exercise) or higher (i.e., maximal-effort 720-kJ TT) power output during exposure to 4300 m after staging compared to before staging. The lack of change in HR and RPE during cycle maintenance training (both SS exercise and 180-kJ TT) as well as no change in the 180-kJ TT performance duration during the staging phase and in comparison to SL suggests also that the endurance fitness level of the volunteers was maintained and not improved while living at the USAFA.

Ventilatory acclimatization and hemoconcentration help raise arterial oxygen content which, in turn, facilitates oxygen transport and delivery to metabolic active tissues, reduces the physiological strain and perceived exertion during SS exercise, and improves exercise tolerance (14). The significant association between improved TT performance and changes in exercise S_aO_2 compared to a lack of association with changes in [Hb] suggest that ventilatory acclimatization was the more beneficial factor resulting from staging, as has been previously proposed for relatively short exposures to altitude (17,22). Ventilatory acclimatization also has been implicated as a major factor responsible for the much lower incidence and severity of AMS and improved endurance performance at 4300 m for both acclimatized SLR (2,3,10) and moderate altitude residents (MAR) (11,16) compared to initially unacclimatized SLR.

The large TT performance improvement at 4300 m was associated with an increased capability to perform at a higher mean exercise intensity (i.e., higher % $\dot{V}O_{2peak}$) after staging compared to before staging (45% vs. 37%) that was independent of changes in AMS symptoms. However, even after partial acclimatization resulting from staging, exercise intensity at 4300 m remained much lower than the 59% of $\dot{V}O_{2peak}$ observed at SL. In contrast, MAR who lived for nearly 2 yr at 2200 m and who likewise performed the 720-kJ cycle TT within hours of exposure to 4300 m (11) did not experience any reduction in exercise intensity (~58% at both elevations). Exercise S_aO_2 at 4300 m also was significantly higher ($P < 0.05$) for the MAR (80%) than for the SLR even after staging (76%). Unfortunately, between-study differences such as resident altitude and fitness level do not allow exact comparison of changes in TT performance between the MAR and staged SLR after rapid ascent to 4300 m. Nevertheless, at 4300 m, a lack of reduction in exercise intensity and a higher S_aO_2 for the MAR indicate that while the degree of acclimatization and the TT improvement experienced by the staged SLR in the present study were significant, they likely were less than complete.

In summary, staging of previously unacclimatized SLR at a moderate altitude of 2200 m for 6 d greatly improved TT performance during subsequent exposure to 4300 m. The improvement in TT performance occurred independently of changes in AMS. The elevation and duration of the moderate altitude sojourn used were not so high to significantly raise the incidence and severity of AMS, yet were sufficient to induce beneficial changes that subsequently improved TT performance at high altitude. The association between improved TT performance and changes in exercise S_aO_2 suggest that ventilatory acclimatization was the major factor contributing to the improvement. Moderate altitude staging would be useful for military personnel or search and rescue teams who may be required to perform physically demanding tasks immediately on insertion to higher elevations.

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